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LABORATORY TESTING AND EVALUATION OF IODINE-RELEASING
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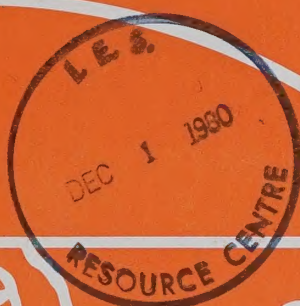
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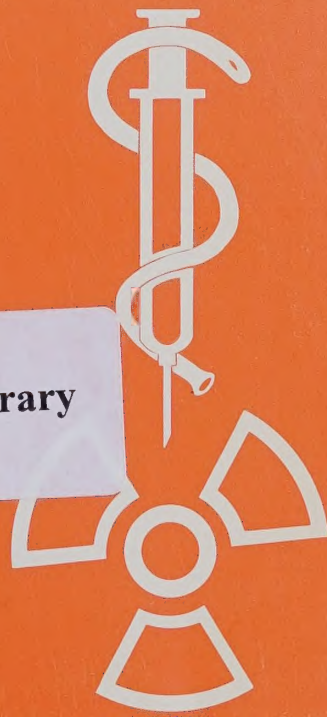
laboratory testing and evaluation of iodine-releasing point-of-use water treatment devices



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**LABORATORY TESTING AND EVALUATION OF IODINE-RELEASING
POINT-OF-USE WATER TREATMENT DEVICES**

Environmental Health Directorate
Health Protection Branch

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RÉSUMÉ

Deux types d'appareils servant à purifier l'eau au point d'utilisation, à l'aide de l'iode, ont été mis à l'épreuve et évalués. Le premier type d'appareil est essentiellement un réservoir contenant des cristaux d'iode, dans lequel se forme une solution saturée d'iode qui est ensuite introduite dans l'eau par un réseau de conduites et de soupapes. Cet appareil peut décharger une quantité de 0.5 à 1.0 mg d'iode/L d'eau pendant de longues périodes si la concentration en iode est vérifiée et ajustée toutes les semaines. Une étude de la documentation révèle que cette concentration en iode et un temps de contact adéquat (au moins 15 minutes dans l'eau chaude et au moins 30 minutes dans l'eau froide dont la température est inférieure à 7°C) produisent une eau suffisamment pure.

Le deuxième type d'appareil est une cartouche de résine au triiodure qui permet un contact étroit entre les microorganismes et le support contenant l'iode. Lorsqu'on utilise une flore microbienne mixte provenant des eaux d'égout contenant de 1000 à 5000 coliformes totaux/100 mL comme indicateur, on ne peut pas garantir l'innocuité de l'eau de boisson traitée par cet appareil. La quantité d'iode résiduel mesurée est trop faible et le temps de contact trop court pour assurer une désinfection convenable.

L'iode est un élément physiologiquement actif et, parce qu'il peut produire des effets défavorables lorsqu'il est consommé en quantités excessives pendant de longues périodes, son utilisation n'est recommandée qu'occasionnellement ou en cas d'urgence. Lorsqu'on l'emploie, la qualité microbiologique de l'eau brute doit se situer dans les limites acceptables pour le traitement classique de l'eau; on doit veiller, en outre, à ce que le temps de contact soit adéquat et les teneurs en iode optimales. À cette fin, la quantité d'iode résiduel doit être mesurée au moins une fois par semaine au moyen d'instruments d'essai précis.

SUMMARY

Two types of point-of-use water treatment employing iodine for disinfection were tested and evaluated. The first type consists essentially of a container of iodine crystals, which, by means of tubes and valves, doses a stream of saturated iodine solution into the tap water. This device was found capable of delivering a dose of 0.5 - 1.0 mg of iodine/L of water over long periods of time if the iodine concentration was tested and adjusted weekly. A review of the literature showed that this concentration of iodine and an adequate contact time (at least 15 minutes in warm water and at least 30 minutes in water colder than about 7°C) provide an adequately disinfected water.

The second type of unit is a resin triiodide cartridge that allows close contact of the microorganisms and the iodine-containing matrix. When challenged with mixed sewage microorganism containing 1000-5000 total coliform bacteria/100 ml., the unit was found to be incapable of delivering safe, potable water. The measured iodine residuals and the contact times were too low to ensure adequate disinfection.

Iodine is a physiologically-active element and, because of the possibility of adverse effects when excessive levels are consumed over long periods of time, it is not recommended for other than occasional or emergency use. Where it is employed, the raw water microbiological quality should be within the range acceptable for conventional water treatment, and adequate contact times and optimum iodine levels must be provided. This requires at least weekly measurement of the iodine residual with an accurate test kit.

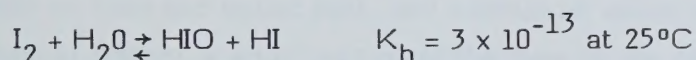
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INTRODUCTION

Point-of-use water treatment devices have become popular in recent years because of increased outdoor recreational activities such as camping, use of cottages and summer homes and the interest by the general public in health-related aspects of food and water. The Bureau of Chemical Hazards of the Environmental Health Directorate has published a survey and test protocols for point-of-use water treatment devices (1). This document outlines principles of operation of most commonly-used devices and presents proposed test protocols that are designed to ensure that devices are effective for their intended purpose and do not in any way contaminate water in doing so. These test protocols have been used to examine ultraviolet light disinfection devices and the results have been reported (2). The present study considers two types of iodine-containing units that are intended for the disinfection of raw (microbially-contaminated) water. One unit is a patented resin triiodide (RTI) unit that releases iodine into the water as it passes through the resin bed. The other is an iodine dosing (ID) unit that delivers a stream of saturated iodine solution into the main-stream flow of water at a specified dosage, usually 0.5-1.0 mg/L free iodine residual.

Iodine, a nonmetallic element with an atomic weight of 126.92 is the only halogen that is solid at room temperature. It dissolves slightly in water (29 mg in 100 g of water at 20°C). Of the naturally-occurring halogens, iodine has the highest atomic weight, the lowest oxidation potential, the lowest water solubility, and hydrolyzes to the least extent in water. In solution in water, iodine may exist in the form of elemental iodine (I_2), as hypiodous acid (HIO) or as hypiodite ion (IO^-), and, in the presence of excess iodide, as the triiodide ion (I_3^-). The hydrolysis of iodine proceeds as:



The hypiodous acid may then dissociate with variation in pH to form hypiodite ions:



The relative proportions of I_2 , HIO and IO^- vary according to the pH of the water. This has little effect on the disinfecting properties of the solution, however, as HIO and IO^- have similar bactericidal properties.

It has been well established that elemental iodine (I_2) and hypiodous acid (HIO) are effective disinfecting agents (3, 5). Iodine has been used in drinking water supplies under emergency situations (6), and on an experimental basis, in prison supplies (7, 8). Comparisons between chlorine and iodine disinfection have shown that free chlorine (as $HOCl$) is five times more virucidal and four times more cysticidal than HIO and is 200 times more virucidal and two times more cysticidal than I_2 (9). On the other hand, a free chlorine residual is often difficult to maintain, particularly in the presence of ammonia. Since iodine does not combine with ammonia to form iodamines, the free iodine residual is established easier and maintained longer.

It has been demonstrated that the bacterium Escherichia coli can be devitalized in less than four minutes by 0.1 - 0.2 mg/L of I_2 or HIO, whereas viruses may require ten minutes with 0.5 mg/L HIO; I_2 is relatively ineffective on viruses at usual dosages and contact times (8). Cysts of Entamoeba histolitica require 1-2 mg/L of I_2 or HIO for an extended contact period of 10-60 minutes. Because the dosages and contact time requirements for iodine are well known, and little affected by normal drinking water composition, no attempt was made with the iodine dosing unit to duplicate these results. Rather, the iodine residual was measured in the treated water for its concentration and stability, as well as the degree of attention required to obtain the desired levels of 0.5-1 mg/L iodine in the water. In addition, the test kit supplied with the unit for the iodine residual measurement was tested against a standard reference method.

The resin triiodide cartridge system has not been as well studied as the elemental iodine dosing methods. Therefore, in addition to testing the iodine residuals from the unit, a challenge of sewage bacteria was used to determine whether there was sufficient bactericidal action to produce water acceptable according to the Guidelines for Canadian Drinking Water Quality (10).

MATERIALS AND METHODS

Description of Devices Tested

(a) RTI Unit

The resin triiodide unit is housed in one of three plastic cartridges that comprise the complete raw-water treatment unit. The first cartridge is a woven fibre fines filter to remove small particles such as dirt, rust, or scale down to 10 μm . The second cartridge utilizes activated carbon to remove taste and odour from the water, and was not employed during this study, since the objective of the present study was to assess disinfecting ability only. The third cartridge, the resin triiodide unit itself, is a sealed, disposable unit that contains a patented polystyrene divinylbenzene quaternary ammonium anion exchange resin that has been substituted with the triiodide (I_3^-) ion. The stated lifetime of this cartridge is about 378 500 L. The unit is designed to treat raw water and has no stated requirement for holding tanks or other means of increasing contact times. The connections allow 3/4 inch (1.9 cm) pipe to be used with working pressures of up to 689 KPa (100 pounds per square inch).

A test Kit provided with the system employed mercuric chloride and o-tolidine as a qualitative measure of iodine residual in the treated water. The RTI unit was tested periodically with this test kit to ensure that it was functioning properly.

(b) ID Unit

The iodine dosing unit is a rather simple device comprising a plastic container of KI crystals with an inlet and outlet port, and a series of valves and tubing (see Figure 1). Using the valving system, a small portion of the flow of the water supply passes through the plastic tank and forms a saturated iodine solution. The saturated solution is introduced into the main supply where it is diluted to a desired concentration. By using the test kit supplied to monitor the iodine concentration in the water and an inline plastic needle valve on the effluent side of the unit, the desired iodine concentration (0.5 - 1.0 mg/L) can be obtained. Instructions with the device indicate that flow restrictors and holding tanks should be employed, as required, to ensure a 15-minute contact time with the iodine.

The unit purchased had a 1.4 kg (3 pound) crystal iodine capacity; at a dosage of 0.5 mg/L, this should treat 2.7×10^6 L of water. Iodine crystals should be added to the unit when they are observed to be about 2/3 depleted.

Operation of Test Manifold

The ID and RTI units were run in parallel using a common manifold system as shown in Figure 1.

Water for the test system was Mississauga, Ontario city water that was limited to 345 KPa (50 p.s.i.) by a pressure regulator. A valve was manually opened and closed daily to provide 19 hours off water flow and 5 hours on seven days a week. The water flowed through two activated carbon filters in series. The flow was regulated using an in-line valve and the flow through the system was indicated by an in-line rotameter. An inserted dial type thermometer was used to monitor the water temperature. A timer-controlled solenoid valve was used to divert the water flow between two parallel streams in the test system. The timer was adjusted to operate on a 10-minute cycle where the flow was directed through the ID unit for one minute and through the RTI unit for nine minutes.

(a) Iodine Dosing Unit

This unit was operated on the above-described duty cycle seven days a week for five weeks with the unit on from 2 p.m. to 9 a.m. each day and off between 9 a.m. and 2 p.m. The unit was adjusted as instructed by the manufacturer to deliver an initial concentration of 0.72 mg/L of iodine in the flow of 17.8 L per minute treated water. Samples were taken three days per week at 0, 0.5, 1 and 3 minutes after the start up of the "on" cycle of the unit. To obtain a sample at three minutes, the timer was manually overridden to prevent the flow from being diverted to the RTI system. Samples were taken of the raw feed water after the carbon filters to provide a blank for the iodine test.

The iodine residual was determined by using the DPD iodine test method and also the wet test kit supplied with the unit. A detailed comparison of these methods is described below.

(b) Resin Triiodide Unit

This system was operated five days per week on a duty cycle of 19 hours "on" and 5 hours "off" with water flowing through the unit with a cycle of 90 percent "on" and 10 percent "off". Stagnation periods of no water flow through the unit were introduced for 53 hours at 23, 46, 69 and 92 percent of the rated lifetime of the unit.

The unit was dosed with a bacterial challenge for the last hour of its operation during the 19-hour operating part of the cycle prior to the 5-hour shutdown time. The unit was again dosed for the first half-hour after start-up during the period when the samples were taken. Samples of the raw sewage challenge and the dosed water supply were taken. Two samples were collected at 0, 0.5 and 5 minutes after the start of the "on" cycle. One sample was analyzed for total coliform count while the other was used to determine iodine residual. This cycle was repeated until the expected lifetime of the unit, 455 000 L, had been exceeded.

Dosing was accomplished by using an educator inserted in the water flow. A peristaltic pump was used to supply approximately 4.5 mL/min of the raw sewage challenge. The

challenge was constantly stirred during the dosing by a magnetic stirrer. This pump was replaced on the 15th day of testing by a diaphragm pump due to a failure in the original motor's control.

At the beginning of each start-up cycle, the test system was cleared of air in the lines and the flow was adjusted to approximately 17.8 L per minute.

Polyethylene piping and plastic fittings were used throughout the test system and all joints were teflon taped to ensure that no leaks would occur during the testing.

All samples to be analyzed for bacteriological parameters were collected in 250 mL clear glass bottles which contained sodium thiosulphate to provide a final concentration of 100 mg/L in the sample. This was added to the bottles to remove any traces of disinfectant possibly present in the sample water. Samples for analysis of iodine residual were collected in 200 mL plastic beakers for analysis.

The Challenge Bacteria

For the purposes of testing, a sample of domestic sewage was obtained daily from a pilot sewage treatment plant at the Ontario Research Foundation. This sewage was screened through a 25 micrometre nytex filter to reduce suspended solids and clumps of bacteria. Where dilution of the sewage was necessary to achieve the required total coliform dosage of 1000 - 5000 counts per 100 mL, phosphate buffered water, (11) was used as a diluent. This solution was used for dosing during testing at start-up time and then stored at 4°C overnight for use again in the pre-shutdown dosing period of 60 minutes.

Samples were taken at the same time of day in order to minimize diurnal variations in total coliform levels.

Microbiological Methods

Total coliform counts were performed by the membrane filtration technique on m-Endo LES agar (11). In order, however, to maximize recovery of total coliforms following treatment with a water purification unit, 0.1 percent peptone water supplemented with 0.7 percent glutamate was substituted for the buffered water used for diluting and washing the sample. Following the filtration of sample, the 47 mm (0.45 µm pore size) gridded membrane filters (Type GN-6, Gelman Corporation) were incubated on m-Endo LES agar (Difco Laboratories, Detroit) in a 35°C incubator (Thelco, Precision Scientific, Chicago) for 24 ± 2 hours. Colonies, with the characteristics appearance as described in Standard Methods (11) were counted.

Total plate counts on 1 mL aliquots were performed on Tryptone Glucose Extract (TGE) agar by a spread plate procedure. Prior to performing the test, TGE agar was prepared, autoclaved and aseptically dispensed in 25 mL portions into 15 x 100 mL petri plates. The plates were then incubated at 41.5°C for several hours until a two-to-three gram weight loss occurred.

Appropriate dilutions of sample were made in phosphate buffered water. One millilitre aliquots of the diluted sample were inoculated in a spiral fashion onto the surface of the pre-dried TGE agar plates. When the water was absorbed by the agar, the plates were inverted, placed in a sealed plastic container, and incubated at room temperature ($20 \pm 2^\circ\text{C}$) for seven days. The colonies were then counted with the aid of a Quebec colony counter.

Determination of Residuals

(a) Chlorine

The total available chlorine content of the water passing through the two activated carbon filters, and serving as test water for these experiments was performed by the diethyl-p-phenylene diamine (DPD) method (12), using a colour comparator.

(b) Iodine

The iodine residual (expressed as an equivalent concentration of I_2) was measured by four methods:

(i) The leuco crystal violet method (11) was used as the reference method for all determinations. A spectrophotometer was used to measure the absorbance at 592 nm.

(ii) The DPD method (12) was used with the ID unit to determine the iodine residuals. A colour comparator was used.

(iii) A test kit included with the ID unit, and employing a colour card for quantifying the residual, was tested against the reference methods noted above.

(iv) A test kit included with the RTI unit was used to qualitatively determine the presence or absence of a detectable residual in the water from the unit.

RESULTS

Resin Triiodide Unit

(a) Challenge Bacteria

The raw settled sewage provided a relatively stable source of coliforms to determine the bactericidal efficacy of the resin triiodide cartridge. Over the test period, the mean total coliform count was 15.2×10^6 per 100 mL with a standard deviation of 6.2×10^6 (Table 2). This stability was considered to be as good as that obtained by means of stock cultures of a single bacterial species, and more desirable because of the species heterogeneity.

(b) Test Water

Before the actual test runs of the RTI Unit, the test water, treated to remove residual chlorine by two activated carbon units in series, was tested for its toxicity to the coliform bacteria (Table 3). On days 1 and 2, the water was somewhat toxic to coliform bacteria; a 1.5-2 log decrease in bacterial numbers was obtained within 60 minutes of contact with the water as compared with a phosphate buffer (17) control. No free available chlorine was detectable after passing tap water through carbon filters, so the inhibitory effect was probably due to the presence of a slight combined chlorine residual. This problem was eliminated by installing fresh activated carbon filters. The next toxicity test (day 5) demonstrated that the same coliform count was obtained with the water diluent as with phosphate buffer, and that the count was stable for 45 minutes at least (Table 3).

(c) Performance of the RTI Unit

The mean flow rate through the device was 19.6 L per minute during operating periods over the 37-day study (Table 4). Thus, the minimum expected lifetime of the unit, 378 500 L (100 000 U.S. Gallons), was exceeded in about 28 days and at the end of the test, the minimum lifetime was exceeded by about 38 percent (total volume of 548 000 L). The water temperature during the winter months of the test ranged from 5°C to 8°C (Table 4). In general, the iodine residuals, measured by the DPD method, were very low after three days into the test. Most were, in fact, below the detection limit of 0.36 mg/L of the DPD method. They were, however, positive by the qualitative test kit supplied with the device, designed to indicate that the water was still being adequately treated by the unit.

The geometric means of the bacterial counts in the dosed test water were 3352 total coliforms and 2752 in the total plate counts. Bacterial counts in the finished water varied from undetectable levels (0 percent survival) to influent levels (100 percent survival) for coliforms (Table 5). Total coliform levels were generally lower in the first flow (0 min) than in the later (0.5, 5.0 min) samples. Total plate counts did not show as much variation

with sampling times. The survival values (Table 6) in the 0.5 and 5-minute samples ranged from about 17 percent to 100 percent for coliforms and 10 to 100 percent for total plate counts.

Iodine Dosing Unit

The ID unit was operated for 35 consecutive days at 10 percent "on" time. At 19 hours/day and seven days per week, and a flow rate of 18.2 L/min, the total volume of water treated was 72 500 L. This is equivalent to approximately three percent of the capacity of the 1.4 kg of iodine crystals in the unit (total capacity is about 2.7×10^6 L at 0.5 mg/L dosage rate). There was little fluctuation from the mean temperature of 6.5°C (range 5.0 - 9.0°C) throughout the test (Table 7) that could have influenced the iodine dosage by virtue of the increased solubility of iodine at higher temperatures. To determine the stability of the iodine dosage, the unit was first regulated to between 0.5 - 1.0 mg/L in the treated water as measured by the test kit. The sample taken at 1 minute after start-up was used for this purpose. It was not subsequently adjusted until day 17. During this period, the iodine levels fluctuated up and down according to the test kit results, whereas the DPD method showed a definite downward trend, and was below the detection limit at times. A certain amount of halide background was present in the feed water and this was subtracted from the DPD readings. In subsequent weeks, there was better agreement between the test kit and DPD methods, and the residual was easily maintained at a level between 0.5 and 1.0 mg/L by once-weekly adjustments.

In order to determine the accuracy of the two methods used to determine the iodine residuals in this study, they were both tested against known iodine standards (11). The DPD method was linear to 3.0 mg/L and in good agreement with the standards (Table 8). It also was in good agreement with the more sensitive leuco crystal violet reference method. The kit, on the other hand, gave results about 50 percent lower than both the DPD results and the iodine standards. This, and the fact that the kit method depends upon the somewhat difficult comparison of colour between a liquid sample and printed colour chips for quantitation, explain, to some extent, the lack of agreement of the two methods for iodine determinations observed in Table 7.

DISCUSSION

Iodine is a well-established disinfectant, capable of producing potable water when used in sufficient doses and for adequate contact times. This appears to hold true not only for situations where iodine is dosed into the water, but also where resin triiodide columns are used and the microorganisms come in intimate contact with the material as they pass through the resin bed. This is in contrast to one published study that a detectable iodine residual in the water was not required to kill E. coli, other bacteria, and viruses when an experimental quaternary ammonium ion-exchange resin triiodide was used (13). The resin triiodide column tested here delivered an iodine residual that was below that required for adequate water disinfection. Additionally, no provision was specified or provided for an extended contact period between the iodine and the organisms in the water. The result was that little bacterial reduction was obtained, the treated water being unacceptable for drinking according to the Guidelines for Canadian Drinking Water Quality - 1978 (10). The capacity of this cartridge would seem to be inadequate to purify water in the way in which it was used. Further, even if dosages of 0.5-1.0 mg/L iodine could be obtained by greatly decreasing the flow rates or using larger cartridges, the lack of a sufficient contact time would likely preclude adequate disinfection of the water. Presumably, these measures, and the provision of a holding tank with at least 15 minutes retention time would provide adequate disinfection with a water temperature above 7°C; below this temperature, retention time of at least 30 minutes should be provided (1). The advantages of the resin triiodide systems (speed and convenience) would, however, be lost by use of these modifications.

The data provided here on the resin triiodide system would indicate that units containing this agent should not be treated differently from any other iodine-releasing unit, that is, the ability to provide the required iodine residual in the water for extended periods of operation and the provision of a sufficient contact time should be ensured. The present studies revealed the lack of both of these requirements by the RTI unit.

The examination of the more conventional iodine dosing unit was performed with respect to the ability of the device to deliver preset dosages of iodine over an extended time period. There are available, usually at considerably higher cost, pump delivery systems for saturated iodine solutions (14) that do not depend upon the precise water-stream splitting method employed in the unit studied. White (9) has recommended that iodine-dosing systems should be limited to the metering pump types because of their inherently better reliability in delivering a precise constant dosage. A preliminary study carried out in Canada (15) reported serious problems with the regulation of iodine dosage and the bactericidal effectiveness of a water-stream splitting unit in turbid water (5 JTU). The turbidity was implicated in the ineffectiveness of iodine in disinfecting the water as well as the fouling of the valves involved in dosing the iodine into the water.

The present study did demonstrate some instability in the dosage delivered and at least weekly testing and adjustment of the dosage were required. In practice, this could prove to be more tedious than many consumers would be willing to accept and the needed adjustments might not always be made. Long periods of inattention could allow the dosage to vary excessively from the required dosage; either inadequate or excessive iodine levels in the treated water would be the result.

The desirability of the use of iodine for water purification over long periods of time has been the subject of serious debate, mainly because of the physiological action of iodine. Iodine is an essential element in the body and is required to prevent goitre (16). On the other hand the intake of excessive (usually therapeutic) levels of iodine has been shown to cause iodism (an allergic reaction in sensitive persons), Jod-Basedow, iodine thyroiditis, or enlargement of the thyroid with or without hypothyroidism (17). Studies have been performed to determine the effects of ingestion of iodine treated water for several years (7, 8). There has been no convincing medical evidence of adverse health effects or altered thyroid function. In a review of the problem the World Health Organization International Reference Centre for Community Water Supply (17) concluded that iodine disinfection should be limited to emergency use because of the risk of overdose. It should be noted, however, that they were considering highly polluted waters with a high iodine demand in which a high total iodine concentration would be required in order to obtain the necessary free iodine residual for disinfection.

The requirement for iodine in the human body is about 100-300 $\mu\text{g/day}$, depending upon age, sex and activity (18) with 2000 $\mu\text{g/day}$ being considered the toxic level (19). If 400 μg of iodine per day is considered the average dietary uptake for adults (20) and the average water consumption taken as 2 L per day, then any total iodine dosage in the water in excess of 0.8 mg/L would result in a total daily intake above this toxic level. As this leaves no margin of safety for iodine ingestion nor for disinfection purposes, it is considered that iodine disinfection of drinking water should be reserved for emergencies or short-term use such as in weekend cottages. For longer exposure periods, iodine removal, by activated carbon filters for example, might be considered, although the long-term efficacy of these filters for this purpose has not been well established.

As with other point-of-use water treatment devices, the quality of the raw water being treated must be carefully examined in order to ensure that adequate water quality will result. Although iodine is less sensitive to the presence of organics and ammonia than is chlorine, some water may have a very significant iodine demand. This is one reason why the use of an accurate test kit for iodine residual determination is so important. The kit should be employed in setting up the initial iodide residual concentration, and once the system is adequately stabilized, the concentration of iodine in the treated water should be verified, and adjusted if necessary, at least once per week. Additionally, it is important that raw water which is excessively contam-

inated with fecal pollution and pathogenic organisms not be used as the source for potable water. As a general guideline, water containing more than 1000 total coliform bacteria per 100 mL or 100 fecal coliform bacteria per 100 mL should not be used as the drinking water source for point-of-use water treatment devices. This corresponds to the maximum level suggested for conventional treatment of municipal water (10) and represents a value over which the risk of illness in the event of equipment failure or other events, is excessive. In addition, since turbidity in the water can interfere with disinfection, it should be established that the turbidity can be maintained below the maximum acceptable concentration of 5 NTU and preferably closer to the objective of 1 NTU (10).

RECOMMENDATIONS

1. Because iodine is a physiologically-active element, the use of iodine for treatment of drinking water is not recommended for other than occasional or emergency use.
2. Water selected for treatment should be within the treatment range for conventional technology, containing no more than 1000 total coliforms or 100 fecal coliforms per 100 mL. Advice should be sought from the appropriate health agency on the adequacy of the proposed treatment system. Bacteriological analysis should be performed on the raw and treated water periodically.
3. The iodine treatment system should include a reasonably accurate and precise test kit that measures free iodine residual. The kit should be used to establish and maintain correct iodine levels in the treated water. Testing should be performed at least once per week or as frequently as necessary.
4. All units utilizing iodine for disinfection should be tested for their ability to provide an appropriate iodine level in the water and sufficient contact time for disinfection. Generally 0.5-1.0 mg/L with a minimum contact period of 15 minutes is sufficient with warm water. When water temperature may be less than about 7°C, at least 30 minutes contact should be provided. Additionally, a 5 µm filter may be required to eliminate cysts.

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TABLE 1

OPERATION OF RTI AND ID UNITS

Water Flow Through System: on 19 hours per day (2 p.m. until 9 a.m.)
off 5 hours per day (9 a.m. until 2 p.m.)

RTI Unit: on 9 minutes }
off 1 minute } five days per week

every 5 days of operation there is an extended shut-down period of 53 hours.

ID Unit: On 1 minute }
off 9 minutes } seven days per week for five weeks

Bacterial Challenge

RTI Unit: system is dosed for the last hour of operation from 7 to 9 a.m. each day of operation and during the collection of samples between 2 p.m. and 2:30 p.m. daily

Sampling

RTI Unit: samples of water for chemical and bacteriological analysis take at 0, 0.5 and 5 minutes after start-up, five days per week

ID Unit: samples taken at 0, 0.5, 1 and 3 minutes of ON period three times per week

TABLE 2

VARIATIONS IN TOTAL COLIFORM COUNT
OF RAW SEWAGE

Day	Total Coliform Count per 100 mL
1	24×10^6
2	11×10^6
5	16×10^6
6	15×10^6
7	13×10^6
8	14×10^6
12	12×10^6
13	23×10^6
14	18×10^6
15	7×10^6
19	20×10^6
21	16×10^6
22	6×10^6
23	12×10^6
25	10×10^6
26	14×10^6
27	13×10^6
28	12×10^6
29	13×10^6
34	12×10^6
35	10×10^6
36	11×10^6
37	21×10^6
40	25×10^6
42	33×10^6

TABLE 3
TOXICITY TESTING OF CARBON FILTERED WATER ON
TOTAL COLIFORM BACTERIA

Day	Time Elapsed after Sample Dilution (min)	Total Coliform Count per 100 mL with Phosphate Buffer as Dilution Water	Total Coliform Count per 100 mL with Carbon Filtered Water as Dilution Water
1	0	24×10^6	18×10^5
	15	ND	5×10^5
	60	17×10^6	5×10^5
	90	20×10^6	2×10^5
2	0	11×10^6	12×10^5
	15	ND	5×10^5
	60	9×10^6	1×10^5
5 (Fresh carbon filter)	0	19×10^6	18×10^5
	15	ND	19×10^6
	45	ND	19×10^6

ND - Not Done

TABLE 4
FLOW RATES AND IODINE RESIDUALS
WITH RESIN TRIIODIDE UNIT

Day	Flow Rate L/min	Feed Rate mL/min	Water Temp (°C)	Iodine Residual: DPD Method (mg/L)		
				t = 0 min	t = 0.5 min	t = 5 min
1	20.4	4.2	5.5	0.72	0.72	0.72
2	18.2	4.2	6.5	1.1	1.1	1.1
3	13.2	5.0	6.0	0.90	1.1	1.1
4	11.3	5.0	6.0	<0.36	<0.36	<0.36
7	18.2	6.5	9.0	<0.36	<0.36	<0.36
8	18.2	6.5	7.5	<0.36	<0.36	<0.36
9	18.2	6.5	7.0	<0.36	<0.36	<0.36
11	18.2	6.5	7.0	<0.36	<0.36	0.36
14	18.2	6.5	7.0	<0.36	0.36	0.36
15	18.2	6.5	6.0	<0.36	<0.36	0.36
16	18.2	6.5	6.0	<0.36	0.36	0.36
17	18.2	6.5	6.0	<0.36	<0.36	<0.36
18	18.2	6.5	7.0	<0.36	<0.36	0.36
23	18.2	5.0	6.5	0.36	0.36	0.36
24	18.2	5.0	6.5	0.72	0.72	0.72
25	15.9	5.0	6.0	<0.36	0.72	<0.36
28	15.9	5.0	6.0	<0.36	0.36	0.36
29	15.9	5.0	6.5	0.36	0.36	0.36
30	15.9	5.0	5.5	<0.36	0.36	0.36
35	13.6	5.0	5.0	<0.36	<0.36	<0.36
36	13.6	5.0	6.0	<0.36	<0.36	<0.36

TABLE 5

BACTERIOLOGICAL PERFORMANCE OF THE RESIN TRIIODIDE UNIT

Date	Bacterial Challenge Solution		Counts of Dosed Water Before Treatment		Counts After Treatment - (minutes after unit start-up)					
					0 min		0.5 min		5 min	
					Total Coliform Count/100 mL	Total Plate Count/mL	Total Coliform Count/100 mL	Total Plate Count/mL	Total Coliform Count/100 mL	Total Plate Count/mL
1	31 x 10 ⁵	23 x 10 ⁵	400	800	7	350	480	500	670	
2	12 x 10 ⁵	11 x 15 ⁵	330	300	1600	730	110	140	250	
3	40 x 10 ⁵	49 x 10 ⁵	1800	790	1010	820	970	1150	570	
4	100 x 10 ⁵	95 x 10 ⁵	2800	1160	500	1590	1400	1800	790	
7	190 x 10 ⁵	42 x 10 ⁵	7100	2800	310	16 400	5100	4100	1200	
8	170 x 10 ⁵	137 x 10 ⁵	13 000	5700	5500	6200	3300	3700	1380	
9	110 x 10 ⁵	66 x 10 ⁵	3000	1400	24	1230	2700	2500	1160	
10	56 x 10 ⁵	19 x 10 ⁵	1500	360	<2	300	1600	1700	290	
11	40 x 10 ⁵	39 x 10 ⁵	1700	880	4	590	1700	1700	780	
14	38 x 10 ⁵	41 x 10 ⁵	1500	1030	6	350	1300	1100	1030	
15	42 x 10 ⁵	66 x 10 ⁵	1500	1260	6	560	1400	1600	730	
16	32 x 10 ⁵	45 x 10 ⁵	2100	1510	<2	570	2000	1800	930	
17	30 x 10 ⁵	74 x 10 ⁵	2800	7900	<2	39	640	800	820	
18	70 x 10 ⁵	81 x 10 ⁵	3100	2900	1500	4500	1300	1500	960	
23	49 x 10 ⁵	78 x 10 ⁵	1300	5400	10	1290	4600	2300	3600	
24	60 x 10 ⁵	56 x 10 ⁵	8500	16 000	>8000	>30 000	3300	3400	2100	
25	90 x 10 ⁵	33 x 10 ⁵	7500	7600	3500	7800	3500	3800	7200	
28	90 x 10 ⁵	51 x 10 ⁵	47 000	23 000	2100	5100	>8000	>8000	16 400	
29	40 x 10 ⁵	192 x 10 ⁵	6800	13 800	>8000	19 500	5200	3400	7700	
30	170 x 10 ⁵	111 x 10 ⁵	5900	7100	>8000	>30 000	4400	2300	1500	
35	60 x 10 ⁵	37 x 10 ⁵	10 000	4100	40	310	2400	2500	460	
37	59 x 10 ⁵	63 x 10 ⁵	12 000	11 100	800	1900	2600	5500	5000	

TABLE 6

**SURVIVAL OF BACTERIAL POPULATION AFTER
TREATMENT BY THE RESIN TRIIODIDE UNIT**

Day	After 0.5 Minutes		After 5 Minutes	
	Total Coliform Count Survival (%)	Total Plate Count Survival (%)	Total Coliform Count Survival (%)	Total Plate Count Survival (%)
0	>100	88	>100	84
2	33	31	42	83
3	54	56	64	72
4	50	100	64	68
7	72	>100	58	43
8	25	40	28	24
9	90	87	83	83
10	>100	92	>100	81
11	100	57	>100	89
14	87	93	73	100
15	93	73	100	58
16	95	75	86	62
17	23	19	29	10
18	42	43	48	33
23	>100	82	>100	67
24	39	49	40	13
25	47	>100	51	95
28	>17	96	>17	71
29	76	55	50	56
30	75	>100	39	21
35	24	11	25	11
37	22	35	46	45
Arithmetic mean*	62	67	61	58

*For purposes of Calculations, recoveries of greater than 100% are considered as 100%

TABLE 7

PERFORMANCE OF THE IODINE DOSING UNIT

Day	Water Temp. °C	Time of Sample and Analytical Method							
		t = 0 min		t = 0.5 min		t = 1 min		t = 3 min	
		DPD ^a	Kit ^b	DPD	Kit	DPD	Kit	DPD	Kit
1	5.5	0.36	0.25	0.36	0.25	0.72	0.50	1.4	1.0
2	6.5	1.1	0.50	1.4	0.50	1.4	1.0	1.8	1.0
3	6.0	0.72	1.0	1.1	0.75	1.4	1.5	0.72	0.50
4	6.0	0.72	1.0	0.36	1.50	0.72	2.0	0.36	1.5
7	9.0	0.36	1.50	0.36	2.0	<0.36	2.0	0.72	1.0
9	7.0	<0.36	1.0	<0.36	1.0	0.36	1.50	<0.36	1.0
10	8.0	<0.36	0.50	<0.36	0.50	<0.36	0.50	0.36	1.0
14	7.0	<0.36	0.25	<0.36	0.25	0.36	0.50	0.36	0.50
16	6.0	<0.36	0.25	0.36	0.50	0.72	1.0	0.72	1.0
18 ^c	7.0	0.36	0.50	0.36	0.50	0.72	1.0	0.72	1.0
22	---	0.36	0.25	0.72	0.50	1.1	1.0	1.1	1.0
23	6.5	0.36	0.50	0.72	1.0	0.72	1.0	0.72	1.0
25	6.0	0.36	0.25	0.72	0.25	0.72	0.50	0.72	0.50
28	6.0	<0.36	0.25	0.36	0.25	0.72	0.50	0.36	0.25
29	6.5	0.36	0.50	0.36	0.50	0.72	0.75	0.72	0.75
35	5.0	0.36	0.50	0.36	0.50	0.36	0.50	0.72	0.75

a. The diethyl-p-phenylene diamine method

b. The test kit supplied with the ID Unit

c. On Day 17, the valve was readjusted to deliver approximately 0.75 mg/L iodine

TABLE 8

COMPARISON OF METHODS FOR IODINE DETERMINATIONS

Standard (mg/L Iodine)	Iodine Residual (mg/L)	
	DPD Method	Kit
.1	0.1	0
.5	0.5 ^a	0.25
1.0	0.9 ^b	0.5
1.5	1.4	1.0
3.0	3.1 ^c	2.0

a. Colour comparator reading between 0.36 and 0.72.

b. Colour comparator reading between 0.72 and 1.1.

c. Colour comparator reading between 2.9 and 3.2.

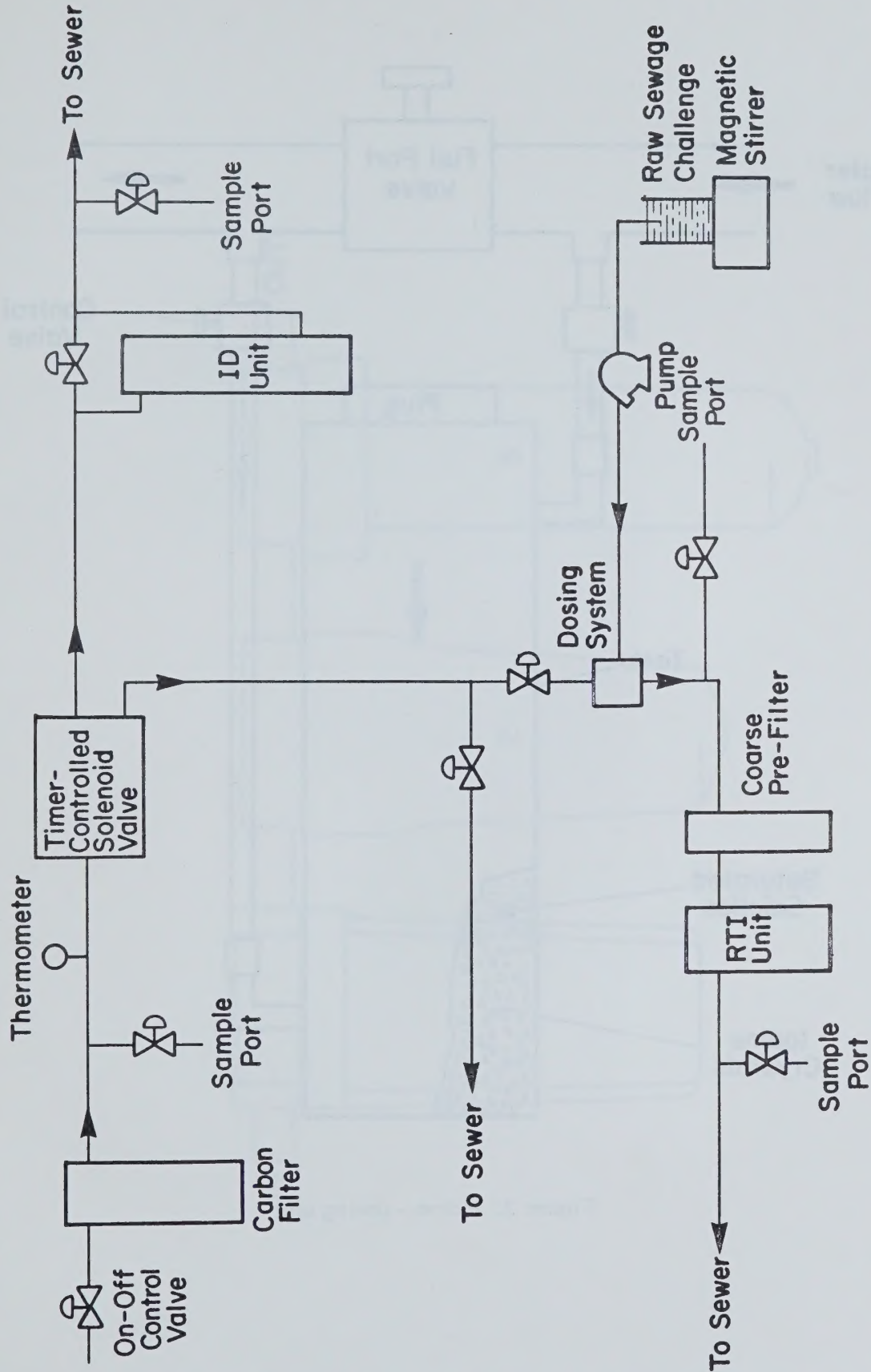


Figure 1. Schematic diagram of test manifold

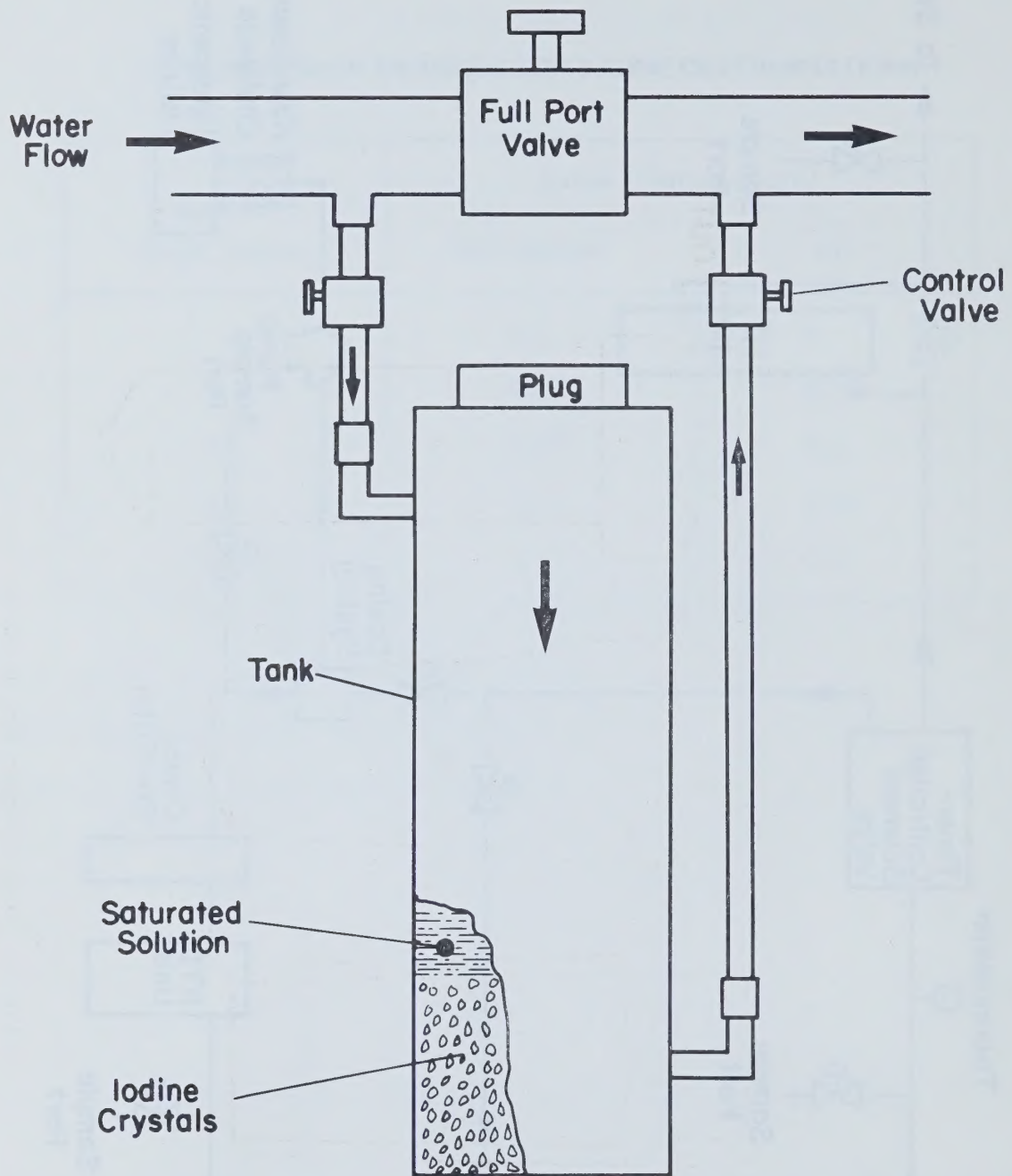


Figure 2. Iodine - dosing unit

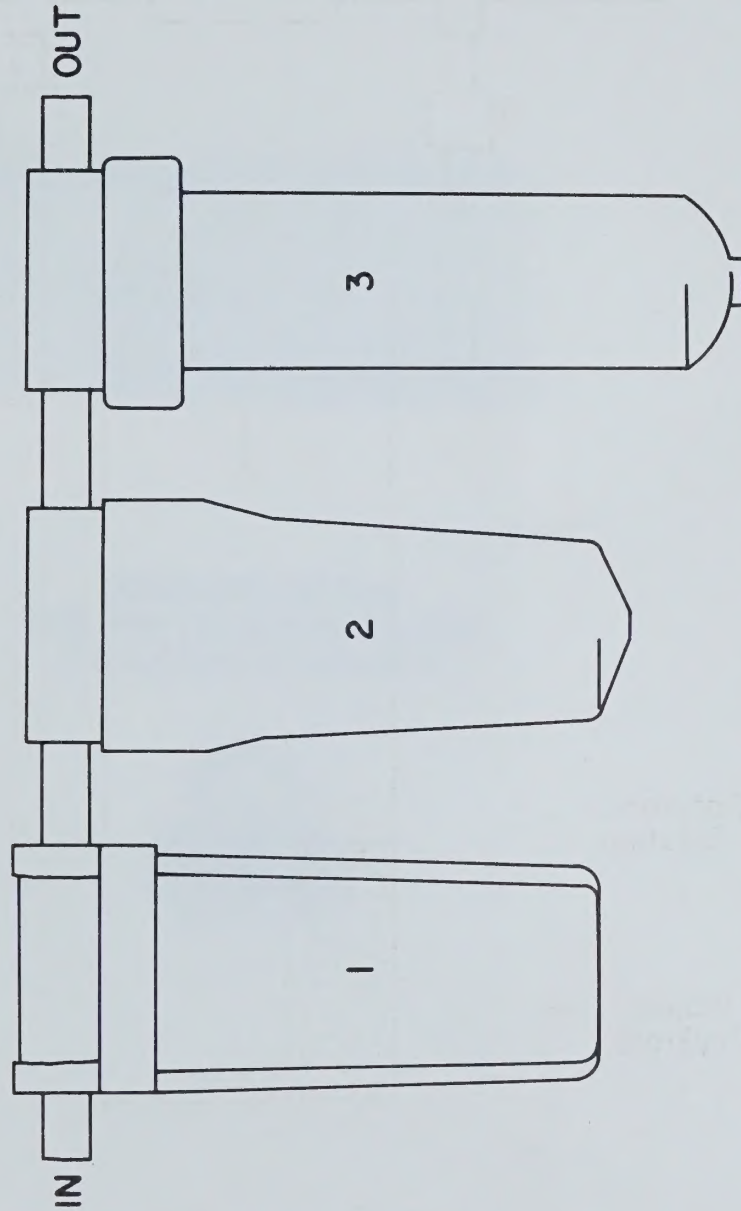


Figure 3. Resin triiodide system components
(1. Fines filter, 2. Activated carbon filter,
3. Resin triiodine cartridge)

CAI HW 1180E46

Canada. DNHW. EHD.

80-EHD-46

LABORATORY TESTING AND EVALUATION OF IODINE-B
DINE OR-ICE WATER TREATMENT DEVICES. 1980.

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